# Millions of Single Cloud Weak Mg II Systems

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**Abstract.** We report on a population of absorption systems selected by the presence of very weak Mg II doublets. A sub–population of these systems are iron enriched and have near solar metallicities. This would indicated advanced stages (i.e. few Gyr) of in situ star formation within the absorbing structures. From photoionization modeling, we infer low ionization fractions of $f(\text{H I}/\text{H}_{\text{tot}}) \simeq 0.01$, and gas densities of $\sim 0.1$ cm$^{-3}$. Since the maximum H I column densities are $\sim 10^{17}$ cm$^{-2}$, the inferred cloud sizes are $\sim 10$ pc. From their redshift number densities, this implies that their co–moving spatial density outnumbers normal bright galaxies by a factor of a few million.

## 1 What Good are Mg II Systems?

The strong, resonant Mg II $\lambda\lambda 2796, 2803$ doublet provides a sensitive tracer of gas in the universe, sampling environments over five decades of neutral hydrogen. Mg II allows the cosmological tracking of damped Ly $\alpha$ absorbers (DLAs, $N(\text{H I}) > 10^{20.3}$ cm$^{-3}$), Lyman limit systems (LLS, $N(\text{H I}) > 10^{17.3}$ cm$^{-3}$), and so–called sub–Lyman limit systems (sub–LLS, $N(\text{H I}) < 10^{16.8}$ cm$^{-3}$). Mg II also traces the presence of early–epoch star formation, since magnesium is a product of Type II supernovae (SNe), enriching surrounding absorbing gas clouds on time scale of a few Myr.

Often, Fe II and C IV transitions are present in Mg II "selected" systems; their strengths relative to Mg II and each other vary. The presence of iron in some systems suggests more advanced star formation processes, such as Type Ia SNe that enrich their surroundings on time scales of a few Gyr. Strong C IV in some systems suggests density structure in the clouds, since Fe II and C IV cannot simultaneously survive photoionization by the similar radiation fields [see Churchill, et al. (1999) and Rigby, Charlton, & Churchill (2001)].

## 2 Observational Properties

The population of Mg II absorbers so–called "weak systems" are isolated in redshift, have rest–frame equivalent widths less than 0.3 Å, and exhibit single clouds with line widths unresolved at HIRES/Keck resolution ($\Delta v = 6$ km/s). In Figure 1, we present examples of three single–cloud weak systems (SCWS) and one weak Mg II system with an additional very weak cloud on the blue wing ($z = 1.229$). The data been converted to rest–frame wavelengths.

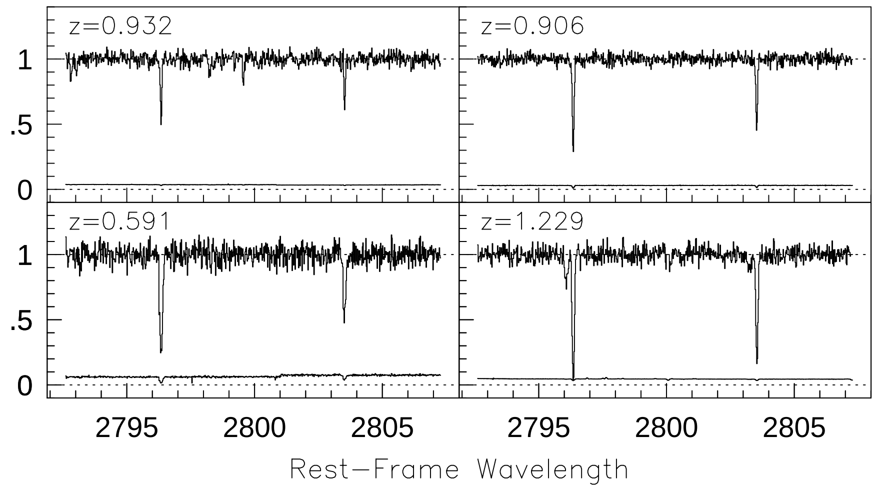


Figure 1: Four weak Mg II absorbing systems (presented in the rest frame) at redshifts between 0.5 and 1.3. The data were obtained with the HIRES instrument at the W. M. Keck Observatory.

For $W > 0.02$ Å, the equivalent width distribution follows a power law according to $n(W) = CW^{-1}$. The redshift path density outnumbers that of Lyman–limit systems by a factor of three; that is, statistically 65% of *all* Mg II systems are optically thin in neutral hydrogen (Churchill et al. 1999). This has been verified observationally by measuring the lack of a Lyman limit break in many weak systems (Churchill et al. 2000).

## 3 Inferred Properties

Details of the results presented here are given in Rigby, Charlton, & Churchill (2001). In that work, we found two classes of SCWS: those that are Fe–rich and those that are Fe–poor (see Figure 2), demarcated by $\log N(\text{Fe II})/N(\text{Mg II}) = -0.3$. We summarize our results as follows:

- The metallicities are greater than $0.1Z_{\odot}$.
- The Fe–rich systems have a low ionization parameter ($\log U = \log n_{\gamma}/n_{\rm H}$) of $\simeq -4.5$, high density of $\log n_{\rm H} \simeq -1$ cm$^{-3}$ (assuming [$\alpha$/Fe] = 0), and small cloud sizes of $d = 10$ pc.
- The Fe–poor clouds are less constrained and have $-4 < \log U - 2$ and $-3.5 < \log n_{\rm H} < 1.5$ cm$^{-3}$ (where can be in range [$\alpha$/Fe] = 0 to +0.5), and sizes in the range of $10 < d <$ few kpc.

- Seven of the 15 systems require multiple ionization phases, due to C IV and/or Lyman $\alpha$ absorption strengths.

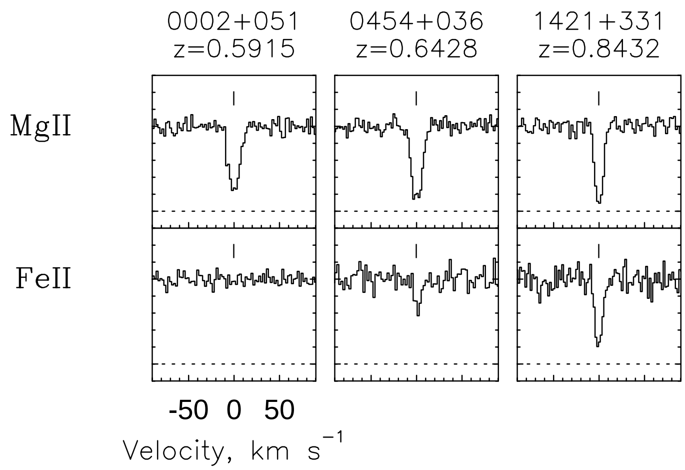


Figure 2: Example of three weak Mg II absorbing systems, each with a very different Fe II strength. The $z = 0.59$ system would be considered Fe–poor and the other two Fe–rich.

## 4 Astronomical Implications

Because weak systems are optically thin to neutral hydrogen, we know that their maximum allowed $\log N(\mathrm{H~I})$ is 16.8 cm$^{-2}$. If we enforce the clouds to have no greater than solar metallicity, then the cloud column densities cannot be much less than $\log N(\mathrm{H~I}) = 15.8$ cm$^{-2}$. Allowing for the uncertainty in the slope of the neutral hydrogen column density distribution over this range of column densities (Weymann et al. 1998), we find that somewhere between 25–100% of the $z \sim 1$ Lyman $\alpha$ forest is significantly metal enriched (greater than 0.1 $Z_{\odot}$; also see Churchill & Le Brun 1998).

$$\frac{n_{ws}}{n_{gal}} = \mathrm{few} \times 10^6 h^{-2} \quad \mathrm{Mpc}^{-3}. \tag{1}$$

If we consider the sub–set of systems which are Fe–rich, we find an astronishing result about the spatial number densities, $n$. Based upon their redshift number densities, $dN/dz$, we find

$$n = 10^7 \left(\frac{1\mathrm{pc}}{R}\right)^2 h \ \mathrm{Mpc}^{-3}, \tag{2}$$

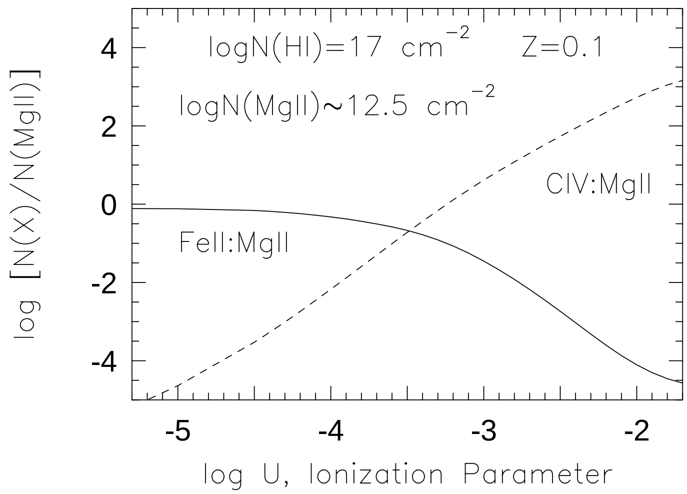


Figure 3: Column density ratios with ionization parameter for Fe II and C IV relative to Mg II. For a near unity ratio of Fe II to Mg II, the ionization parameter is very low,corresponding to a gas density of $\sim 0.1$ cm$^{-3}$.

where $R$ is the cloud size. The Fe–rich systems have very low ionization conditions (or the Fe II would not survive, see Figure 3). This means that $N(\mathrm{H\ I}) \sim 0.01 N(\mathrm{H})$ and that the clouds have relatively high densities, $n_{\mathrm{H}} \sim 0.1$ cm$^{-3}$. The cloud size scales as $R = N(\mathrm{H})/n_{\mathrm{H}}$. For low–ionization, sub–Lyman limit systems, we have $R \simeq 10$ pc. Thus, from Equation 1, we find $n \simeq 10^5 h$ Mpc$^{-3}$. Galaxies have $n \simeq 0.04 h^3$ Mpc$^{-3}$. We infer that the ratio of Fe–rich weak systems to galaxies is

Because of the strong presence of iron and high metallicities, the objects hosting the observed absorption very likely experienced advanced stages of star formation (i.e. $\sim 1$ Gyr with contributions from Type Ia SNe). Are we tracking the elusive, old Population III star clusters, or the theoretically predicted dark mini-halos?

## References

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